Black anglerfish (*Lophius budegassa*): weight-length relationships, weight conversion factors and condition factor trends from a decade of two stocks, in ICES Div. VIIIc-IXa (northern Iberian Atlantic waters) and in Div. VIIb,c,h,j,k (Celtic Sea, south-western Ireland and Porcupine Bank)

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Abstract

Weight-length relationships, weight conversion factors and condition factor are presented from a decade (2006 to 2015) for both stocks of black anglerfish (*Lophius budegassa*) in northern Iberian Atlantic waters (ICES Div. VIIIc-IXa) and in Celtic Sea, south-western Ireland and Porcupine Bank (ICES Div. VIIb,c,h,j,k). A total of 2035 and 1263 specimens were sampled respectively in each stock from commercial landings and research surveys. Total length [Lt (cm)], total weight [Wt (g)], “commercial” weight (gutted with liver) [Wgl (g)] and “scientific” weight (gutted without liver) [Wg (g)] were obtained.

The weight-length relationships for the combined sexes were: $Lt = 0.020\ Wt^{2.916}$; $Lt = 0.017\ Wgl^{2.929}$; $Lt = 0.017\ Wg^{2.922}$ in Div. VIIIc-IXa, and $Lt = 0.025\ Wt^{2.841}$; $Lt = 0.013\ Wgl^{2.984}$; $Lt = 0.013\ Wg^{2.971}$ in Div. VIIb,c,h,j,k.

The conversion factors (total weight - gutted weight), useful in fisheries management due to the commercial landings of this species are available in gutted weight, were: Wt = 1.186 Wgl; Wt = 1.236 Wg in Div. VIIIc-IXa, and Wt = 1.187 Wgl; Wt = 1.233 Wg in Div. VIIb,c,h,j,k.

These updated values can be used in the process of the annual assessment of the state of both stocks in the ICES working group.

The evolution of the condition factor over the year, indicator of nutritional status evolution, is also estimated for immature and mature individuals of each sex, showing some seasonal variation.

The results are similar to the previously estimated in other studies.

Keywords: weight-length relationships, weight conversion factors, condition factor, black anglerfish, *Lophius budegassa*, Northeast Atlantic.

1. Introduction

Black anglerfish (*Lophius budegassa*) is distributed in Eastern North Atlantic from British Isles to Senegal, and Mediterranean Sea. It is a bottom-living and commercially important species for European fisheries, with around 12.000 t in Atlantic waters (ICES Subareas VII, VIII and IX) in 2014 (ICES, 2015).

The annual assessment of the state of the stock in ICES Div. VIIb-k and VIIIa,b,d, and the stock in Div. VIIIc and IXa is performed in the ICES Working Group for the Bay of Biscay and the Iberian waters Ecoregion (WGBIE) (ICES, 2015).

The weight-length relationships allow us to calculate the different weights of individuals which length is known. They are important biological parameters, having a wide application in fish biology and fisheries management, such as for predicting weight from length data, or for the calculation of production and biomass of a fish stock. The conversion factor (total weight - gutted weight) is also useful in fisheries management due to the commercial landings of this species are available in gutted weight. The evolution of the condition factor over the year, indicator of nutritional status evolution, is also estimated and can be related with the spawning process in mature individuals.

Since more than a decade ago, the weight-length relationships and weight conversion factor estimated by Pereda et al. (1998) are being used for the annual assessment process of both stocks of black anglerfish. It would be interesting to estimate updated, and as accurate as possible, parameters in order to continue having the most reliable input data as possible for the stock assessment process. The monitoring of these biological parameters is also interesting for analyzing possible their long-term changes due to the fisheries-induced evolution, climate change or other possible shift in the environmental conditions.

The European institutes cover sampling of biological parameters of this species through Data Collection Regulation (DCR) programme of the UE (Reg EC No1639/2001) since some years ago.

The aim of the study is to improve the knowledge of the biological parameters of black anglerfish, presenting updated information on weight-length relationship, weight conversion factors and condition factor of the following areas of the two main Atlantic stocks of this species: Celtic Sea, south-western Ireland and Porcupine Bank (Div. VIIb,c,h,j,k) and northern Iberian Atlantic waters (Div. VIIIc-IXa2).

These updated values can be used in the process for the stock assessment of the state of both stocks in the ICES working group, replacing those previous estimated.

2. Materials and Methods

2.1. Sampling

The area sampled by Instituto Español de Oceanografía (IEO) covered some of the main areas where the Spanish commercial fleet capture anglerfish: Celtic Sea, south-western Ireland and Porcupine Bank (ICES Div. VIIb,c,j,h,k) (northern stock of the southern shelf) and northern Iberian Atlantic waters (ICES Div. VIIIc-IXa2) (southern stock of the southern shelf) (Fig. 1). Most individuals come from the landings of that fleet, but there were also individuals coming from two research fishing surveys carried out by IEO during the same period and zone. The research surveys “Demersales” (in Div. VIIIc-IXa) and “Porcupine” (in Div. VIIb,c,k) took place in September-October each year of the studied time-series.

The sampling period was a decade, from January 2006 to December 2015. The sampling unit was the quarter, and in this period it was intended to cover the whole length range of this species.

The following collected data from each specimen were analyzed in this study:

- Total length: Lt (cm), length class of 1 cm;
- Total weight: Wt (g);
- Gutted weight (without liver): Wg (g), also named “scientific” weight;
- Gutted weigh with liver: Wgl (g), also named “commercial” weight;

The specimens were mainly obtained by buying ungutted individuals from commercial landings, and on board of commercial and IEO research vessels. The complete data collection for each individual depended on the sampling source, because there are different ways to land and commercializes this species in the fish markets. Specimens landed by the Spanish fleet are already gutted; however, they may or may not have its liver depending on the fish market where they were landed. On the other hand, when the specimens are in poor condition, they have their head cut and their tail is commercialized. As a result of that, the type of commercial weights is quite alike. Therefore, the available range of fish lengths for estimating the weight-length relationship varied according to the type of weight estimated. Thus, the value of total weight was available for a total of

3298 specimens, the gutted weight for 3130 specimens, and the gutted weigh with liver was available for 3090 specimens. The numbers of specimens studied are shown in detail in Table 1, Table 2 and Table 3.

2.2. Data analysis

Weight-length relationships for combined sexes were calculated for the total weight, gutted weight and gutted weight with liver.

Several regression functions were tested and the power function showed the best coefficient of determination (r2) for the three weight-length relationships studied (Wt-Lt; Wg-Lt; Wgl-Lt):

$$W = a\ (Lt)^b$$

where: W= total weight [Wt (g)], or gutted weight [Wg (g)], or gutted weight with liver [Wgl (g)]; Lt = total length (cm); a, b = parameters of the regression.

The different relationships considered for calculation the weight conversion factor for combined sexes were total weight (Wt) - gutted weight (Wg) and total weight (Wt) - gutted weight with liver (Wgl). The function used to relate the weights was a linear function with values “0” to intercept with the x-axis:

$$Wt = a\ W$$

where: Wt = total weight (g); W = gutted weight [Wg (g)], or gutted weight with liver [Wgl (g)]; a = parameter of the regression.

The Fulton´s condition factor was also estimated, which may be an initial approximation for the determination of the spawning period.

$$f = \frac{Wg}{Lt^3}$$

where: f = Fulton´s condition factor; Wg = gutted weight (g); Lt = total length (cm).

Given that there were poor data for obtaining a representative monthly estimation, this parameter was estimated bimonthly for each sex. The condition factor was analysed of both males and females over one-year period, pooling the ten sampled years. In order to find out possible differences between mature and immature individuals two length ranges were distinguished according to the L_{50} value for each sex estimated by Quincoces (2002) for the samples from Div. VIIb-k (41 cm in males and 58.7 cm in females), and the L_{50} estimated by Landa et al. (2014) for those from Div. VIIIc-IXa2 (36 cm in males and 53 cm in females).

3. Results

3.1.Weight-length relationship

The parameters resulting from the fitting of the value pairs (total length and weight) of both sexes combined to the power model were obtained. The coefficients of determination, sample size and length and weight ranges are also shown. The total weight (Wt) - total length (Lt) relationship results for each studied area are shown in Table 1, those of the gutted weight with liver (Wgl) - total length (Lt) relationship are in Table 2, and the gutted weight (Wg) - total length (Lt) relationship is in Table 3. The total weight (Wt) - total length (Lt), gutted weight with liver (Wgl) - total length (Lt), and gutted weight (Wg) - total length (Lt) relationships are plotted respectively in Fig. 2, Fig. 3 and Fig. 4.

3.2. Weight conversion factor

The total weight (Wt) - gutted weight with liver (Wgl) conversion factors for each studied area are shown in Table 4, and those for the total weight (Wt) - gutted weight (Wg) are in Table 5.

Noteworthy is the almost identical Wt-Wgl conversion factor obtained in both areas studied (1.186-1.187). The Wt-Wg conversion factor was also almost identical (1.236-1.233).

3.3. Condition factor

In general, the condition factors of immature individuals ($Lt < L_{50}$) are similar to those of mature ($Lt \geq L_{50}$) only in the first and second quarters, in both males and females and in both studied areas (Fig. 5, Fig. 6). However in the third and fourth quarter, the condition of the immature individuals is clearly better than that of mature individuals.

In the Div VIIb,c,h,j,k,, the evolution of the condition factor of immature individuals over one-year period shows that the better condition is mainly observed in the third quarter, and also in the fourth quarter (Fig. 5). The condition of the mature individuals shows no high differences over the year, although the lower values appear in the first quarter. In the Div.VIIIc-IXa, the evolution of the condition factor of immature males also shows better condition in the third and fourth quarter (Fig. 6). The condition of the mature individuals shows no high differences over the year, although the lower values appear from July to October.

4. Discussion

The collection of samples to estimate the total weight of the specimens is difficult since individuals are landed gutted by the commercial fleet. Collecting the large specimens also is difficult, given their scarcity in the commercial catches.

The presentation of the results from a broad sampling period, pooling the information of a time series (a decade), was considered the most appropriate, as the data of one or a few years did not provide adequate representation of the range of lengths landed of this species.

The parameters here obtained are similar to those obtained in previous studies of black anglerfish whose values are used in the process of stock assessment (Pereda et al., 1998; Quincoces, 2002). However, the number of specimens here collected is higher, in addition to representing a broader range of lengths. These improvements in sampling contribute to obtaining more representative and robust parameters.

4.1.Weight-length relationship

The dispersion of the points (Fig. 2, Fig. 3 and Fig. 4) is greater when using the total weight than using gutted weight. It is mainly due both to the influence of the stomach contents and to the gonad weight in the total weight.

4.2. Weight conversion factor

The weight conversion factors are very useful because the black anglerfish is landed gutted (without liver) in some Spanish fish markets and gutted (with liver) in other ones, and it is important to calculate them for a better estimation of the total annual landing of this species.

The almost equal values of the conversion factor obtained in both areas here studied may be due to this parameter is not influenced by the area where the specimens are. When a wide range of weights and high sample size is analyzed, this parameter seems to be quite homogeneous.

The weight conversion factors here estimated are also within the range of values of previous studies: 1.158-1.208 (Wt-Wgl); 1.193-1.278 (Wt-Wg) (Pereda et al., 1998; Quincoces, 2002). The variability of values among studies may be influenced by the difference in the time period studied, but these differences seem to be more related to the different range of values analyzed in each study.

4.3. Condition factor

Regarding the immature individuals in the stock VIIb-k and VIIIa,b,d, Quincoces (2002) also found in Div. VIIIa,b,d a evolution of the condition factor over the year similar to that here shown in Div VIIb,c,h,j,k, with also higher values in the third quarter. Considering both stocks as a whole, the immature individuals of both sexes show a better condition mainly in summer. Immature specimens do not transfer energy to gonad development, but the good condition in summer may be related to the best environmental conditions and food intake that may favor a more active metabolism. The highest feeding intensity in spring and summer in immature black anglerfish found by Preciado et al. (2006) in Div.VIIIc-IXa supports it.

In mature individuals, low condition was found in the fourth quarter in Div. VIIIa,b,d (Quincoces, 2002). Our results show a small inter-quarterly difference, showing only slightly lower values in the first quarter. The peak of the spawning season in Div. VIIIa,b,d takes place from May to July (Quincoces, 2002), although individuals begin to spawn from January. Thus, both our lower values in first quarter in Div VIIb,c,h,j,k, as those of the fourth quarter of Quincoces (2002) in Div. VIIIa,b,d could be related to a worse condition during the months previous to spawn. Regarding mature individuals in the stock Div.VIIIc and IXa, a slightly lower condition was found in both sexes from September to November (Pereda et al., 1998), similar (though slightly later) to the values from July to October here found. A spawning period from December and July was estimated in Div.VIIIc-IXa (Landa et al., 2014). Therefore this lower values found in these months in this stock could be also related to a worse condition during the months previous to spawn.

In both stocks, these seasonal differences could be due to transference of energetic reserves to the gonadal development in mature individuals, while that energy in immature individuals would be reflected in a better condition.

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Table 1. Total weight (Wt) - total length (Lt) relationships estimated in the present study and those from previous studies currently used in the stock assessment process.

Stock	Author	ICES Div.	Area	Coefficients		n	r^2	Length (cm)		Weight (g)	
				a	b			min	max	min	max
VIIIc-IXa	**Present study**	**VIIIc-IXa**	**Southern Bay of Biscay & Galician waters**	**0,020**	**2,916**	**2035**	**0,986**	**5**	**99**	**4**	**13700**
	Pereda et al. (1998)	VIIIc-IXa	Southern Bay of Biscay, Galician & Portuguese waters	0,021	2,920	1030	0,973	5	89	3	10950
VII-VIIIa,b,d	**Present study**	**VIIb,c,h,j,k**	**Celtic Sea, Southwestern Ireland & Porcupine**	**0,025**	**2,841**	**1263**	**0,987**	**4**	**91**	**1**	**11840**
	Quincoces (2002)	VIIIa,b,d	Northern Bay of Biscay	0,021	2,915	592	0,935	14	84	40	10430
	Pereda et al. (1998)	VIIIa,b,d	Northern Bay of Biscay	0,015	3,004	590	0,994	14	84	40	10430

Table 2. Gutted weight with liver (Wgl) - total length (Lt) relationships estimated in the present study and those from previous studies currently used in the stock assessment process.

Stock	Author	ICES Div.	Area	Coefficients		n	r^2	Length (cm)		Weight (g)	
				a	b			min	max	min	max
VIIIc-IXa	**Present study**	**VIIIc-IXa**	**Southern Bay of Biscay & Galician waters**	**0,017**	**2,929**	**1938**	**0,992**	**4**	**99**	**1**	**11365**
	Pereda et al. (1998)	VIIIc-IXa	Southern Bay of Biscay, Galician & Portuguese waters	0,012	3,019	602	0,989	11	93	15	10800
VII-VIIIa,b,d	**Present study**	**VIIb,c,h,j,k**	**Celtic Sea, Southwestern Ireland & Porcupine**	**0,013**	**2,984**	**1152**	**0,974**	**4**	**91**	**1**	**8368**
	Quincoces (2002)	VIIIa,b,d	Northern Bay of Biscay	0,026	2,818	1229	0,961	14	85	37	8990
	Pereda et al. (1998)	VIIIa,b,d	Northern Bay of Biscay	0,015	2,963	1138	0,996	14	85	36	8990

Table 3. Gutted weight (Wg) - total length (Lt) relationships estimated in the present study and those from previous studies currently used in the stock assessment process.

Stock	Author	ICES Div.	Area	Coefficients		n	r^2	Length (cm)		Weight (g)	
				a	b			min	max	min	max
VIIIc-IXa	**Present study**	**VIIIc-IXa**	**Southern Bay of Biscay & Galician waters**	**0,017**	**2,922**	**1941**	**0,993**	**4**	**99**	**1**	**10972**
	Pereda et al. (1998)	VIIIc-IXa	Southern Bay of Biscay, Galician & Portuguese waters	0,015	2,965	667	0,988	5	89	2	8885
VII-VIIIa,b,d	**Present study**	**VIIb,c,h,j,k**	**Celtic Sea, Southwestern Ireland & Porcupine**	**0,013**	**2,971**	**1189**	**0,989**	**4**	**91**	**1**	**8070**
	Quincoces (2002)	VIIIa,b,d	Northern Bay of Biscay	0,015	2,942	325	0,960	14	79	36	8730
	Pereda et al. (1998)	VIIIa,b,d	Northern Bay of Biscay	0,013	2,989	243	0,996	14	85	37	8990

Table 4. Total weight (Wt) - Gutted weight with liver (Wgl) conversion factors estimated in the present study and those from previous studies currently used in the stock assessment process.

Stock	Author	ICES Div.	Area	Coefficient a	n	r^2	Total weight (g) min	Total weight (g) max	Gutted weight (g) min	Gutted weight (g) max
VIIIc-IXa	**Present study**	**VIIIc-IXa**	**Southern Bay of Biscay & Galician waters**	**1,186**	**1938**	**0,992**	**1**	**13700**	**1**	**11365**
	Pereda et al. (1998)	VIIIc-IXa	Southern Bay of Biscay, Galician & Portuguese waters	1,158	549	0,994	25	10950	15	9650
VII-VIIIa,b,d	**Present study**	**VIIb,c,h,j,k**	**Celtic Sea, Southwestern Ireland & Porcupine**	**1,187**	**1152**	**0,990**	**1**	**11840**	**1**	**8368**
	Quincoces (2002)	VIIIa,b,d	Northern Bay of Biscay	1,177	593	0,981	40	10430	37	8990
	Pereda et al. (1998)	VIIIa,b,d	Northern Bay of Biscay	1,208	590	0,990	40	10430	37	8990

Table 5. Total weight (Wt) - Gutted weight (Wg) conversion factors estimated in the present study and those from previous studies currently used in the stock assessment process.

Stock	Author	ICES Div.	Area	Coefficient a	n	r^2	Total weight (g) min	Total weight (g) max	Gutted weight (g) min	Gutted weight (g) max
VIIIc-IXa	**Present study**	**VIIIc-IXa**	**Southern Bay of Biscay & Galician waters**	**1,236**	**1941**	**0,992**	**1**	**13700**	**1**	**10972**
	Pereda et al. (1998)	VIIIc-IXa	Southern Bay of Biscay, Galician & Portuguese waters	1,193	665	0,995	3	10950	2	8885
VII-VIIIa,b,d	**Present study**	**VIIb,c,h,j,k**	**Celtic Sea, Southwestern Ireland & Porcupine**	**1,233**	**1189**	**0,990**	**1**	**11840**	**1**	**8070**
	Quincoces (2002)	VIIIa,b,d	Northern Bay of Biscay	1,251	244	0,990	40	10430	36	8730
	Pereda et al. (1998)	VIIIa,b,d	Northern Bay of Biscay	1,278	244	0,993	40	10430	36	8730

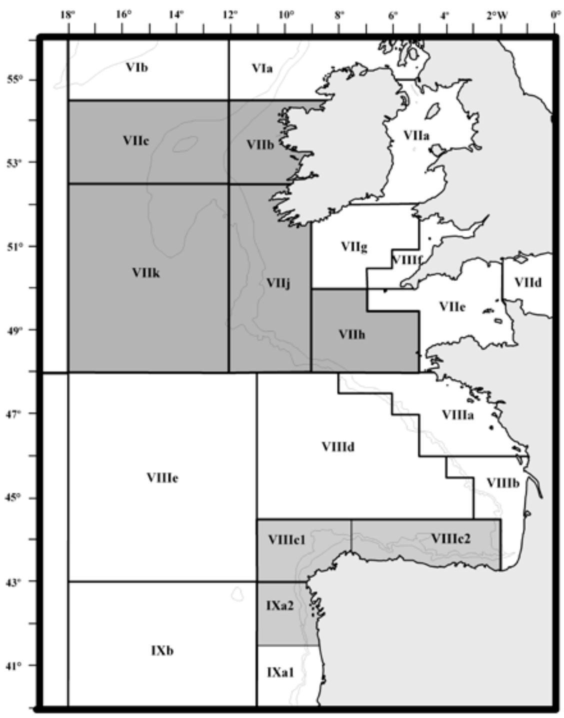

Fig. 1. Sampling ICES Divisions of North-east Atlantic: Celtic Sea, south-western Ireland and Porcupine Bank (ICES Div. VIIb,c,j,h,k) (dark grey); and northern Iberian Atlantic waters (ICES Div. VIIIc-IXa2) (southern stock of the southern shelf) (light grey).

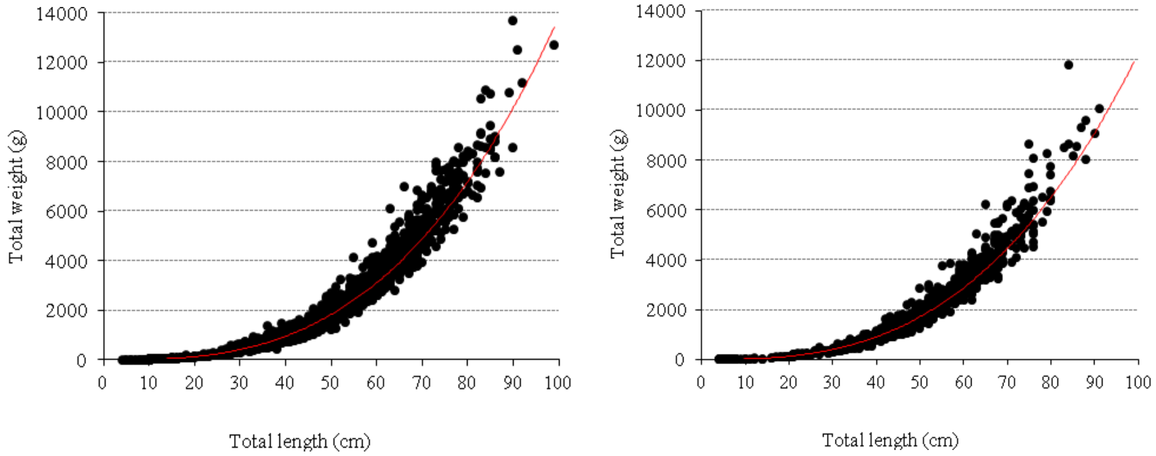

Fig. 2. Total weight (Wt) - total length (Lt) relationships estimated in ICES Div. VIIIc-IXa (left) and Div. VIIb,c,h,j,k (right).

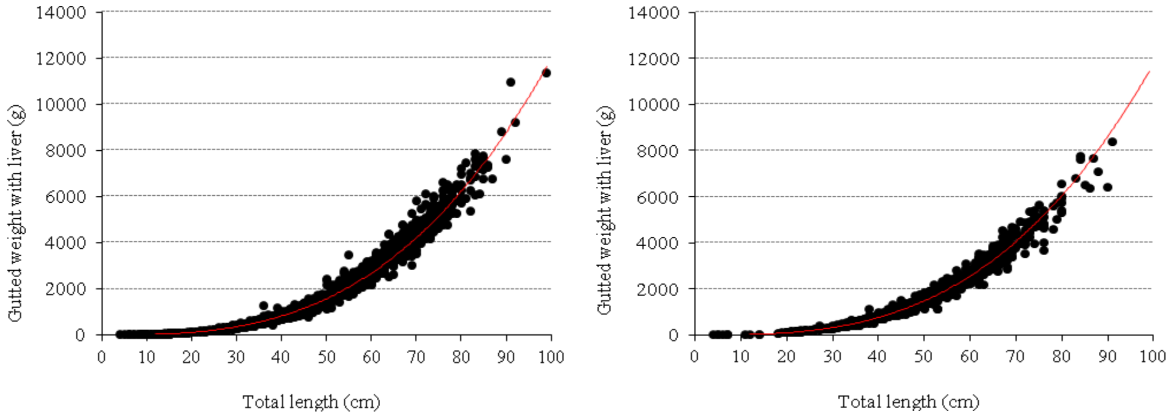

Fig. 3. Gutted weight with liver (Wgl) - total length (Lt) relationships estimated in ICES Div. VIIIc-IXa (left) and Div. VIIb,c,h,j,k (right).

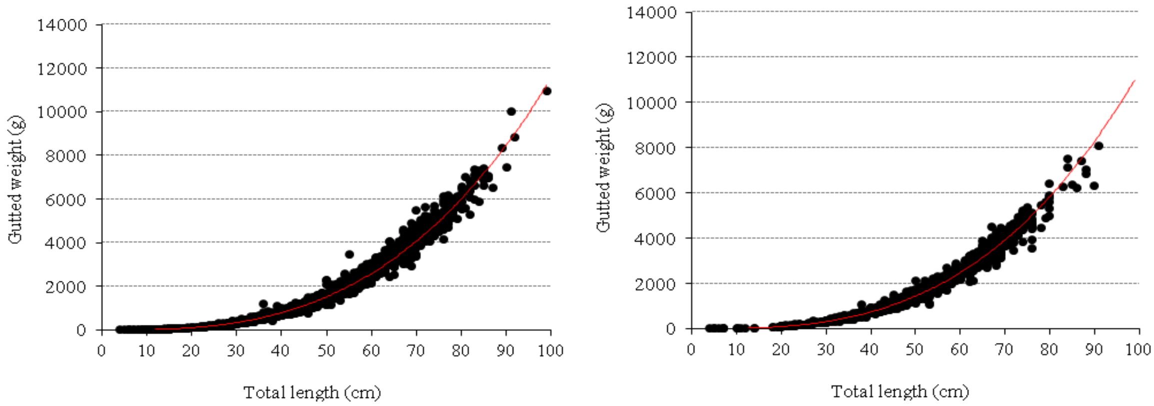

Fig. 4. Gutted weight (Wg) - total length (Lt) relationships estimated in ICES Div. VIIIc-IXa (left) and Div. VIIb,c,h,j,k (right).

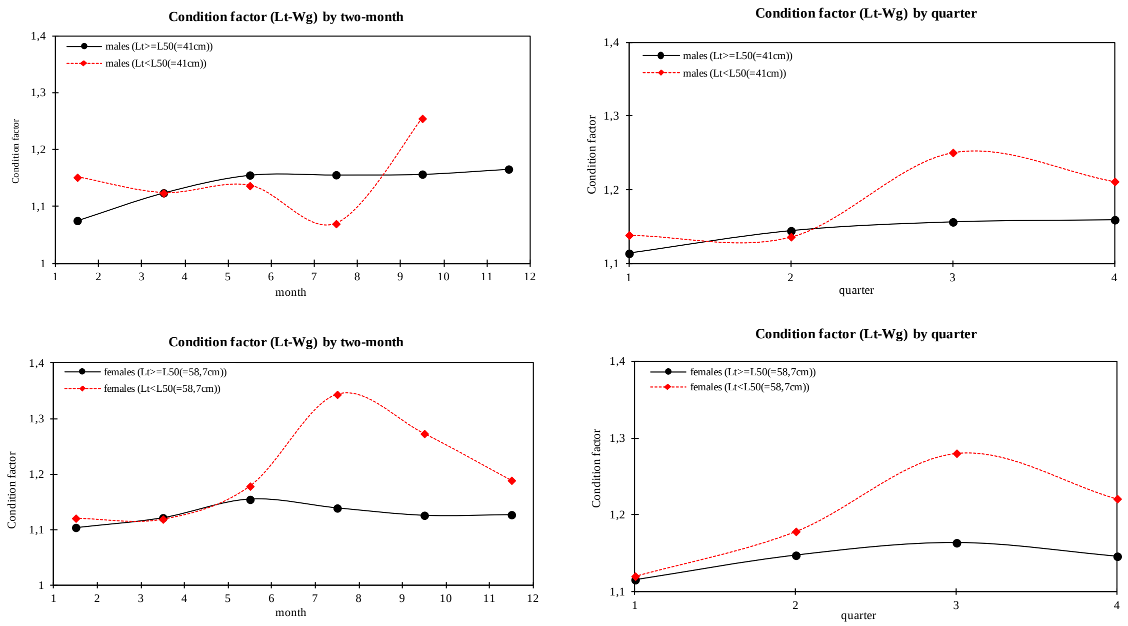

Fig. 5. Evolution of the condition factor for each sex by two-months and quarter in ICES Div. VIIb,c,h,j,k.

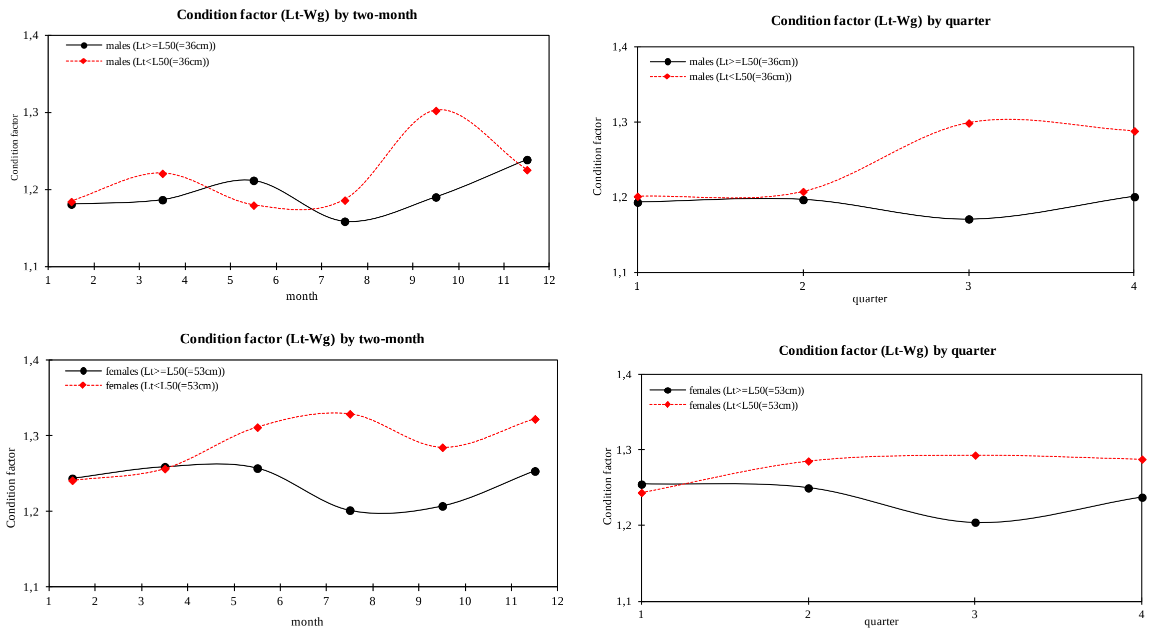

Fig. 6. Evolution of the condition factor for each sex by two-months and quarter in ICES Div. VIIIc-IXa.